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Alternating Magnetic Field Effect on Fine-aggregate Concrete Compressive Strength

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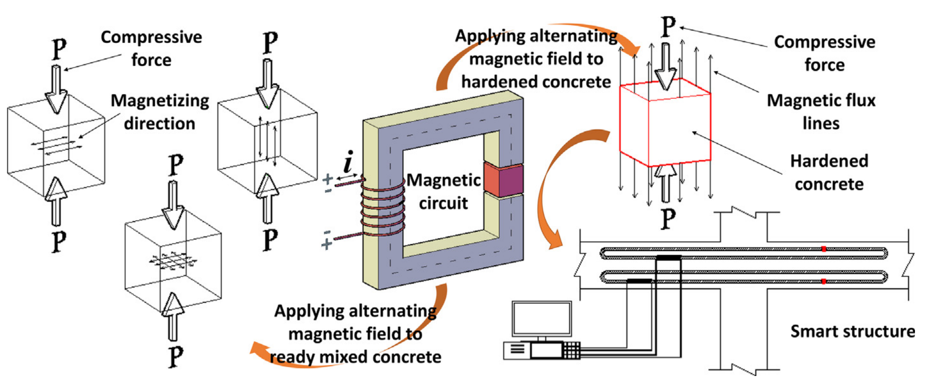
HIGHLIGHTS

- Devising a specialized test setup comprising gapped magnetic circuit.
- Increase in compressive strength by 7.78% due to exposing hardened concrete to AMF.
- A marginal effect of exposing fresh concrete to AMF on the compressive strength.
- The ability of this method as a base for a new generation of smart structures.

GRAPHICAL ABSTRACT



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ABSTRACT

An exploratory investigation was conducted into the feasibility of using Alternating Magnetic Field (AMF) to enhance concrete compressive strength and to invent a new actuators system in smart structures. Hence, some small-scale experiments were performed on cube fine aggregate concrete specimens, wherein the effect of applying AMF of density 0.5 Tesla (T) and frequency 50 Hz to ready mixed and hardened concrete on the compressive strength was examined. Besides, the role of the direction of AMF applied to ready mixed concrete in changing its physical behavior was evaluated. For exposing the specimens to AMF, a specialized magnetic circuit was designed. It was observed that applying AMF to fresh concrete has a marginal effect on compressive strength. But, exposing hardened concrete enhanced the compressive strength up to 7.78%. The advantage of this effect was discussed theoretically from different aspects. It was found that this method can be a base for behavior controlling of large-scale smart concrete structures in real time, through adjusting element stiffness by AMF. Finally, the feasibility of this method for large-scale RC structures was explained, giving a graphical example.

1. Introduction

Enhancing stability of concrete structures is a vital issue in structural engineering having led to invention of different ways such as making structures smart against dynamic forces and improving physical properties of concrete. To attain these goals various methods such as using chemical admixtures and fine aggregate materials known as nano-particles have been widely investigated (for example [1]). Recently, profiting from electromagnetism has been widely used to improve concrete properties.

As to smart structures, electromagnetism has been used mostly in structure performance monitoring [2,3]. Smart structures

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include some sensors and actuators systems comprising smart materials such as Fiber Optics (FOs) [4–6], piezoelectrics [7–9], Magneto-Rheological (MR) materials [10,11], Electro-Rheological (ER) materials [12,13], Shape Memory Alloys (SMAs) [14,15]. The performance of such structures depends on the utilized smart material properties. This technology has been used for applications such as damage detection, shape control [16,17], noise and acoustic control [18,19], health monitoring [20,21], vibration control [22,23], and energy harvesting [24,25]. These techniques, however, have their own shortcomings for example unsuccessfulness at early stages of damage, difficulty in sensor installation, reduction in load-bearing capacity of the element due to taking up too much space in it, distinction between the load bearing system and the sensors [26].

Regarding concrete properties improvement, a novel method is magnetic treatment of concrete water. This method is based on the effect of magnetic field on water properties explained by Lorenz in 1902 for the first time. When water is exposed to magnetic field, the consolidation degree between water molecules decreases and the size of the molecules increases [27], thereby changing some of its physical and chemical characteristics such as viscosity, solubility, temperature, specific weight, surface tension, electric conductivity, PH, permeability pressure [28,29]. Most of studies in this field have concluded that using magnetized water in concrete fabrication increases the compressive strength by 10–25 percent and also improves concrete workability [30–36]. This causes that in some cases, with the same compressive strength and workability, the cement content can be reduced. According to one of recent studies, this reduction can fall to 28% [30]. In addition, using magnetic water in concrete makes it more resistant to freezing and permeating and increases its plasticity [31]. Magnitude of such changes is controlled by some factors such as treatment duration and the power of magnetic field. It is shown that if water is subjected to a magnetic field of intensity 0.985 T for 24 h, the compressive strength can increase up to 55% besides a slight increase in workability [37].

Recently, the effect of applying magnetic field to ready mixed concrete comprising carbonyl iron powder (as MR material [38]) on its fresh-state properties was studied. It was found that this method changes the shear resistance of concrete but has no effect on the compressive strength [39]. According to another recent investigation dealing with the effect of static magnetic field of different powers up to 25.37 Gauss, (1 Gauss = 10^{-4} T), on cement paste properties, at different ages up to 7 days of hardened cement pastes samples, it was found that the amount of Calcium Silicate Hydrate (CSH) gel is larger and its morphology becomes denser and less porous with higher magnetostatic induction strength; magnetic field changes the mineralogical composition of hydrated cement pastes and enhances mechanical strength of cement pastes where the maximum increase in compressive strength equal to 13% was observed as to the 7-day aged specimens having been treated by magnetic field of strength 25.37 Gauss [40].

However, studies on the effect of directly applying magnetic field to cementitious materials on their physical properties are very scarce in technical literature. Moreover, the use of magnetic fields for concrete containing smart materials is almost limited to the effect of static magnetic field applied to fresh cementitious materials on their fresh state properties. Up to the authors knowledge, there have been no studies dealing with (a) the effect of Alternating Magnetic Field (AMF) applied to ready mixed concrete, (b) the effect of the direction of AMF applied to ready mixed concrete, (c) the effect of applying AMF to hardened concrete, on its physical properties.

This study aims to uncover these facts and explore feasibility of making a new generation of smart concrete structures using AMF, performing some small-scale experiments on different fine aggregate concrete specimens. The procedure is divided into two phases: I) the fresh-state phase including the effect of exposing fresh concrete to AMF on the compressive strength; the role of the direction of AMF applied to fresh concrete in hardened concrete behavior, II) the hardened-state phase including the effect of applying AMF to hardened concrete on the compressive strength.

2. Research significance

Different ways for promoting physical properties of concrete have been widely dealt with. However, the authors believe that the effect of directly applying magnetic field to concrete on its mechanical properties as well as the use of magnetic fields in controlling concrete structural behaviors in real time have not been addressed. Hence, the present study is to deal with these issues for the first time. The consequence of this exploratory investigation can be used in real time behavior controlling of smart structures, with financial and practical advantages over some existing methods like no need for actuators systems installation in concrete.

3. Experimental investigation

3.1. Materials

Throughout the investigation the AMF used was of frequency 50 Hz with a magnitude of 0.5 T. The cement used in all the specimens was commercial ordinary portland cement the chemical and physical properties of which are given in Table 1. The aggregates used were air dried river sand of maximum particle size 2.36 mm [0.093 in.]. To improve workability of specimens, all the samples were prepared using superplasticizer with the same dosages. The water mixed was tap water. To avoid from a high amount of magnetic leakage because of the high magnetic permeability of steel materials; and for almost all of magnetic flux to pass through molded fresh concrete, for all specimens plastic molds of thickness 3 mm [0.12 in.] were used.

3.2. Test program

Fifteen fine aggregate concrete specimens were examined for compressive strength. The main variables in the test series include: a) AMF exposure occasion, and b) AMF exposure direction. As to variable (a), the specimens were divided into three types including: Non-Magnetized (NM) specimens which were not exposed to AMF, Pre-Magnetized (PrM) specimens which AMF was applied to fresh concrete immediately after casting concrete into molds, Post-Magnetized (PoM) specimens in which the specimen was exposed to AMF after hardening, during the test. Variable (b) is associated with the PrM specimens, depending on magnetizing direction as explained in Table 2 and shown in Fig. 1.

Table 1
Physical and chemical properties of cement.

Compressive strength, 28 days, MPa	45
Specific surface, Blaine, m^2/kg	300
SiO_2, %	20.6
Al_2O_3, %	5.6
CaO, %	63.0
MgO, %	2.7
SO_3, %	2.3
Na_2O, %	0.6
K_2O, %	0.7
LOI, %	1.7
Fe_2O_3, %	3.95

Note: 1 MPa = 145 psi; 1 m^2/kg = 0.542 yd^2/lb.